Idaho National Laboratory

U.S. Department of Energy FreedomCAR & Vehicle Technologies Program

Advanced Vehicle Testing Activity

Hydrogen Station & Hydrogen ICE Vehicle Operations

Federal Network for Sustainability
Idaho Falls, Idaho – July 2006
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Presentation Outline

- **Background & Goal**
- **Arizona Public Service (APS) Alternative Fuel (Hydrogen) Pilot Plant - design & operations**
- **Fuel Dispensing**
- **Hydrogen & HCNG Internal Combustion Engine (ICE) Vehicle Testing Activities**
- **Briefly, other AVTA Activities**
- **WWW Information**

AVTA Background & Goal

- **Advanced Vehicle Testing Activity (AVTA) is part of the U.S. Department of Energy's (DOE) FreedomCAR and Vehicle Technologies Program**
- **These activities are conducted by the Idaho National Laboratory (INL) & the AVTA testing partner Electric Transportation Applications (ETA)**
- **AVTA Goal - Provide benchmark data for technology modeling, research & development programs, as well as help fleet managers & other vehicle purchasers make informed purchase & operations decisions**

AVTA Testing History

- **Full-size pure EVs (40 models, 5 million test miles)**
- **Neighborhood EVs (15 models)**
- **Urban EVs (3 models, 1.75 million test miles)**
- **Hybrid EVs (11 models, 32 HEVs, 2 million miles)**
- **Hydrogen ICE vehicles (several models, 300k miles)**
- **Oil bypass filter testing (17 vehicles, 1.3 million miles)**

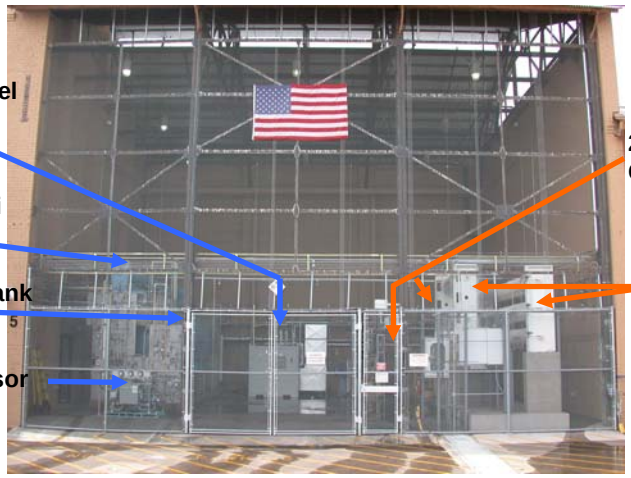
APS Alternative Fuel (Hydrogen) Pilot Plant

- **Partners - Arizona Public Service (APS), ETA, INL, & DOE**
- **First & longest operating hydrogen station in the U.S. – since June 2002**
- **Hydrogen produced onsite**
- **Hydrogen & CNG fueling**

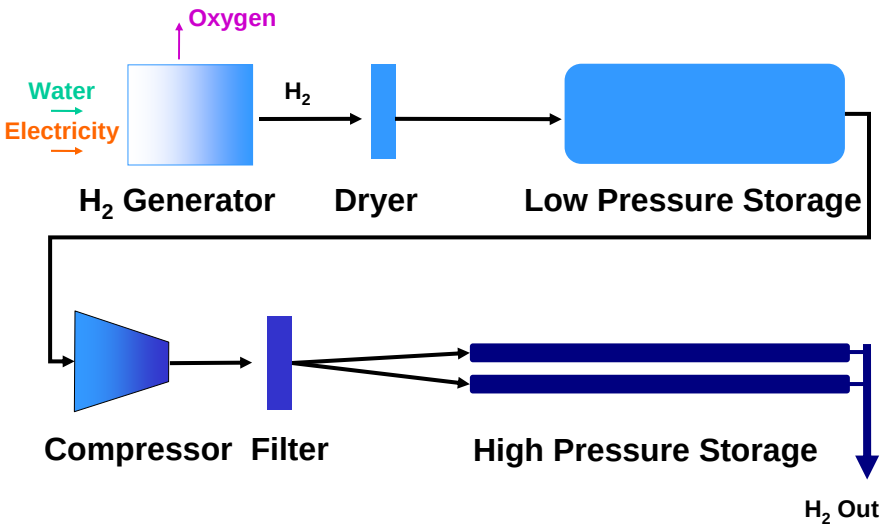
Pilot Plant & Hydrogen ICE Vehicle Testing Objectives

- **Evaluate the safety & reliability of operating ICE vehicles on 100% hydrogen & hydrogen/compressed natural gas (HCNG) blended fuels (15 to 50% HCNG)**
- **Evaluate hydrogen fueling infrastructure operations & costs**
- **Quantify hydrogen & HCNG ICE vehicle costs, performance & emissions**

Pilot Plant - Layout



Pilot Plant - Hydrogen Subsystem



Pilot Plant – Hydrogen System

- Proton Energy Systems' HOGEN PEM stationary fuel cell operating in reverse
  - 300 scfh hydrogen output @ 150 psi
  - 17 kWh per 100 scf hydrogen
- Hydrogen Lectrodryer
  - -80°F dew point
- Pressure Dynamic Consultants (Pdc Machines)
  - 300 scfh @ 6,100 psi
- 8 Norman hydrogen filter locations
- Hydrogen - 99.9997% purity

Pilot Plant - Hydrogen Storage

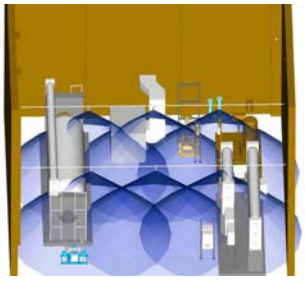
- Low pressure hydrogen storage (lower tank) - 8,955 SCF @ 150 psi
- High pressure hydrogen storage (upper 2 tanks) - 17,386 SCF @ 6,000 psi (total both tanks)

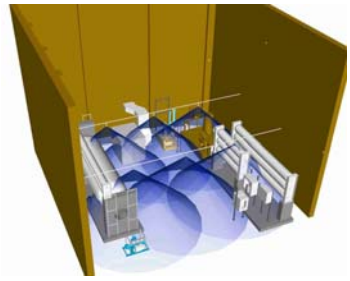
Pilot Plant - Emergency Shutdown System

- Ultra-fast IR/UV detectors
- Combustible gas detectors
- Manual (5) & remote trips
- Vent stack temperature monitor
- Alarms horns & strobe lights
- Vent stack fire suppression

Pilot Plant – Hydrogen Gas Detectors

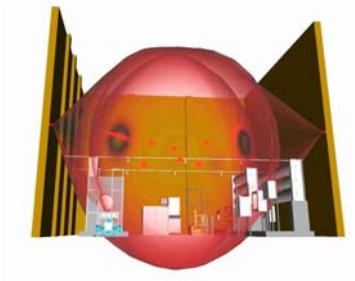
- Six combustible gas detectors (Det-Tronics RS 8471)
- Monitors hydrogen & natural gas in 1% increments of lower flammability limits (LFL)
- Alarm condition at 25% of LFL reached
- Emergency shutdown when 50% of LFL reached

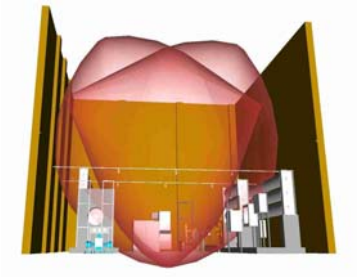




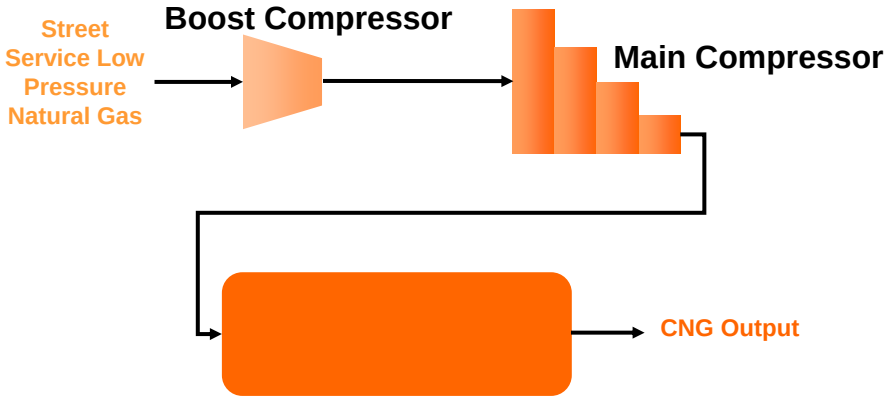
Pilot Plant – Flame Detectors

- Two mid-level (35 feet) & four corner IR/UV flame detectors (Spectrex 20/20LB units)
- One detector at fuel dispenser unit
- If flame detected, emergency shutdown initiated within 3 milliseconds





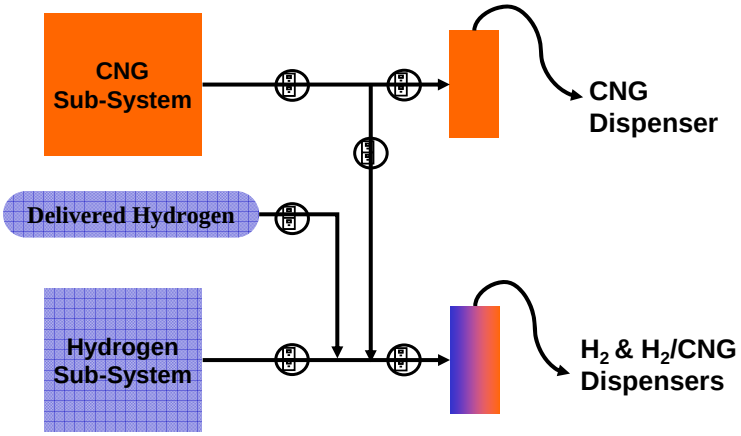
Pilot Plant - CNG Substation



Pilot Plant - CNG System

- CNG Boost Compressor
  - 300 scfm @ 60 psi
- CNG Main Compressor
  - 350 scfm @ 5,000 psi
- CNG Storage/Pressure – 6 tanks
  - 3 Low: 11,079 scf @ 3,600 psi
  - 2 Medium: 5,711 scf @ 4,500 psi
  - 1 High: 5,711 scf @ 5,000 psi
  - Manufacturer: CP Industries

Pilot Plant – Dispenser System



Pilot Plant - Fueling Dispensers

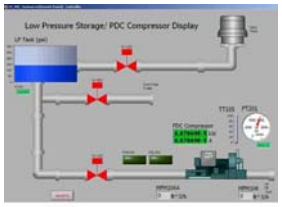
- Includes metering & electronic billing interface
- Fully permitted for motor fuel dispensing
- Public access

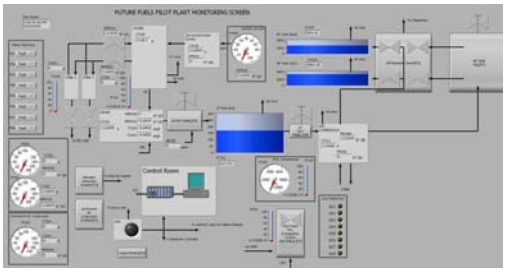
Prototype Dispenser Testing

- Uses proportional flow control valves for hydrogen & CNG gas streams from 100 to 40,000 scfh
- Real-time ratio control of blended fuels - uses coriolis mass flow transducers in hydrogen & CNG gas streams
- 1 Nozzle - CNG & HCNG fuels (15, 20, 30, & 50% hydrogen by volume) at 3,600 psi
- 1 Nozzle - 100% hydrogen at 5,000 psig
- Being commercialized by Clean Energy

Pilot Plant - Monitoring

- 8,000 fueling events & 10,000 kg of hydrogen produced
- Hydrogen kg energy costs based on historical (26% to 49%) & projected (70%) plant factors
  - $3.43 down (26% PF) to $2.39 per kg (70% PF)
  - DOE 2005 energy cost target $2.47
- Water cost per kg of hydrogen $0.10



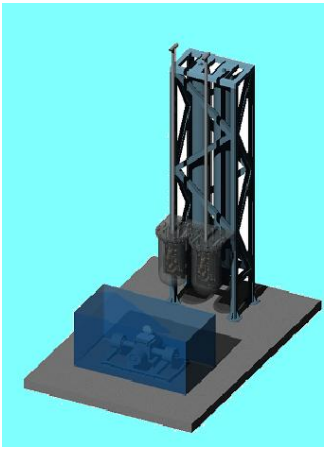


Generation II Station Design

- Driven by commercial fueling station design requirements
  - Reduced setbacks to allow siting on a commercial corner
  - Reduced operator training to allow operation by service station personnel or vehicle operators
  - Reduced hazards to minimize the maximum potential accident
  - Multiple layers of safety to significantly reduce operating risk

Generation II Station Design

- Coaxial Containment System™
- Expandable modular design
- Envelopes most severe environmental conditions
- Exhaustive safety analysis to support permitting
- Zero setback requirements for flexible siting
- Shop assembled skid design
  - Assembly by ASME shop
  - Field welding minimized



Gen II - Coaxial Containment System™

- Double wall piping system
  - Shields process piping within a pressure containing pipe
  - Contains pressure waves resulting from any gas ignitions
  - Redirects any detonations to benign location
  - Allows inerting of annulus to prevent gas ignition
  - Eliminates need for blast setback
  - Protects process pipe from vandalism

Hydrogen & HCNG ICE Vehicle Testing

- Initial ICE hydrogen & HCNG vehicle testing
  - Dodge van on 15% HCNG (operating)
  - Ford F150 up to 30% HCNG (operating)
  - Ford F150 up to 50% HCNG (testing complete)
  - 100% hydrogen Mercedes Benz van (operating)



15% HCNG Dodge Van Emissions Testing

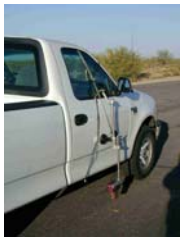
- 5.2 L CNG V8 (no modifications) with 71,000 HCNG test miles - no problems
- 27,000 miles of 15% HCNG fuel data - 15.5 miles/GGE

Percentage change in 15% HCNG emissions compared to 100% CNG emissions	
Total hydrocarbons	-34.7%
Carbon monoxide	-55.4%
Oxides of nitrogen	+92.1%
Carbon dioxide	-11.3%

30% HCNG F150 Testing

- 5.4 L V8 CNG engine – added: supercharger, ignition modifications & exhaust gas recirculator
- Fleet testing - 59,000 30% HCNG miles: 17.3 miles/GGE

Fuel Blend	0 to 60 mph (secs.)	Miles/GGE	Range (miles)
CNG	10.10	23.3	122
15% HCNG	10.97	22.6	110
30% HCNG	12.68	23.5	102



30% HCNG F150 Emissions Testing

Fuel Type	Percentage Change in Emissions Testing					
	NMHC	CH_4	HC	CO	NO_X	CO_2
Gasoline	Base	Base	Base	Base	Base	Base
CNG	-80	+967	+35	-63	-34	-24
15% HCNG	-78	+1000	+40	-70	-26	-27
30% HCNG	-89	+1050	+37	-73	-25	-28

NMHC=Non-Methane Hydrocarbons
HC=Total Hydrocarbons
NOx=Oxides of Nitrogen

CH_4=Methane
CO=Carbon Monoxide
CO_2=Carbon Dioxide

50% HCNG F150 Emissions Testing

- **Modifications**
  - **SVO heads, exhaust intercooler & supercharger**
  - **Exhaust gas recirculator & ignition modification**
  - **Equipped with 3 Quantum hydrogen 3,600 psi tanks with 3 kg total storage**

Percent reduction in emissions (HCNG versus gasoline-fueled F-150)

HC	CO	NO_X	CO_2
-3.5%	-43.3%	-97.0%	-16.7%

HC = total hydrocarbons
CO = carbon monoxide
CO_2 = carbon dioxide
NOx = oxides of nitrogen

HCNG ICE Vehicle Testing

- **APS meter reader fleet 12 Bifuel vehicles (GM)**
  - **1,600 fueling events, 190,000 miles using 10,600 GGE of 15% HCNG**
- **Public Fleet - private party Bifuel conversions**
  - **350 fueling events, 36,000 miles (estimated) using 1,800 GGE of HCNG blends (mostly 15%)**

5.4L 16-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 16-valve Ford/ETEC pickup
- 5 speed transmission, supercharged (3 psi boost), hydrogen fuel injectors, & air-to-water intercooler
- Hardened valves & seats, & forged pistons with 12:1 compression
- Motec fuel & spark controls, lean-burn mode
- Onboard hydrogen storage 3 Dynetek tanks @ 3,000 psi, 6.5 kilograms, aluminum vessel & fiberglass wrap
- Converted by ETEC
- 1,365 lbs payload

5.4L 16-valve 100% Hydrogen ICE Vehicle

- Baseline Performance testing results
  - Maximum speed @ 1 mile: 81 mph & ¼ mile: 58 mph
  - Acceleration (0 to 50 mph): 18.1 seconds
  - SAE J1634 fuel economy (AC on): 14.5 miles/GGE
  - SAE J1634 fuel economy (AC off): 18.0 miles/GGE
  - 45 mph constant speed fuel economy: 27.0 miles/GGE
  - Range 95 (14.5 miles/GGE) to 175 miles (27 miles/GGE)
- Fleet testing - 4,500 miles: 17.4 miles/GGE (110 miles range)

5.4L 32-valve 100% Hydrogen ICE Vehicle

- 5.4L V-8, 100% hydrogen 32-valve Ford/ETEC pickup
- Automatic transmission, hydrogen fuel injectors, 12 pounds supercharger boost & air-to-air intercooler
- Hardened valves & seats, & forged pistons with 11.5:1 compression
- Motec fuel & spark controls, lean-burn mode
- 7,500 fleet testing miles - 14.4 miles/GGE
- Onboard hydrogen storage 3 Dynetek tanks @ 5,000 psi, 15.3 kilograms (230 miles range)
- Converted by ETEC

6L V-8 100% Hydrogen ICE Vehicle

- Base vehicle: Chevrolet 1500HD crew cab (4 door) with 6L V8 CNG engine
- Converted by ETEC/Roush to 100% hydrogen
- 4-speed automatic transmission, electronic port fuel injection, supercharger, liquid-to-air intercooler
- Integration of powertrain control module & development of hydrogen lean-burn control strategies
- Implementation of J1850 communications to maintain seamless integration with existing OEM equipment

6L V-8 100% Hydrogen ICE Vehicle – cont'd

- 10.5 kg 100% hydrogen storage onboard @ 5,000 psi
- 200 Horsepower & 260 lb-ft torque
- Anticipated 15 miles per GGE & range 155 miles
- Targeted to meet NOx requirements for 2007 Tier II, Bin 7 standards
- HC < 10 ppm & NOx < 25 ppm on engine dynamometer
- Nine vehicles produced
- In baseline performance testing
- 8 units to Vancouver B.C.

Hybrid Electric Vehicle (HEV) Testing

- 32 HEVs, 11 HEV models in fleet testing
  - 160,000 miles (36 months) per HEV, 2 of each model
  - Fuel use, maintenance requirements, insurance, licensing & depreciation costs = life-cycle costs
- Baseline performance (track/dyno) testing
  - Beginning & end of life vehicle performance
  - End of life battery performance
- 1.98 million HEV test miles

Plugin HEV (PHEV) Testing

- Collecting fleet data on 7 Energy CS Prius PHEVs
- Obtaining PHEVs for extensive testing, including
  - Energy CS Prius
  - Hymotion Prius
  - Renault Kango
- Likely PHEVs obtained in FY-2007
  - Renault Cleanova
  - Hymotion & Energy CS Escapes
  - Dodge/EPRI Sprinter (late CY-2007?)

Neighborhood Electric Vehicle Testing

- 15 NEVs successfully completed NEVAmerica baseline performance testing (max speed, range, acceleration, braking, charging), includes 8 GEMs
- Fleet testing of 100+ NEVs
- *Guidelines for the Establishment of a Model Neighborhood Electric Vehicle (NEV) Fleet* - Report
- Next test vehicle:
  - Ford Courier class NEV pickup from Roush



Oil Bypass Filter System Evaluation

- **Goal: Examine oil bypass filter effectiveness, & demonstrate & quantify engine oil use reductions**
- **Filters clean partial flow of oil down to 1 micron, have evaporative units, & some with additive packages**
- **Puradyn systems on 8 buses & Refined Global Solutions systems on 3 buses – all 4 stroke)**
- **Puradyn filter systems 6 Tahoes**

Oil Bypass Filter System Evaluation

- **Test oil quality for 28 variables - total base number, oxidation & nitration levels, contaminants (metals, water, soot, & fuel), & track makeup oil use**
- **1.3 million test miles**
- **Oil change avoidance: 90% buses & 90% Tahoes**

INL Alternative Fuel Fleet (318 vehicles)

- 79 B20 motor coach buses
- 7 Dedicated LNG motor coach buses
- 154 Bi-fuel light-duty CNG vehicles
- 52 Bi-fuel E85 (85% ethanol) pickups/SUVs
- 22 Bi-fuel LNG pickups
- 2 Dedicated CNG vans (injector tests Ford & Bosch)
- 2 Dedicated propane light-duty vehicles



INL Alternative Fuel Infrastructure

- INL – 900 sq. mile DOE facility in Eastern Idaho
- Liquid natural gas (LNG) / compressed natural gas (CNG) station at “site”
- CNG station in Idaho Falls
- E85 (85% ethanol / 15% gasoline) station at “site”
- B20 (20% biodiesel / 80% diesel) station at “site”



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http://avt.inl.gov

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